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Review Paper on Hydropedology

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ABSTRACT: A growing body of research suggests that integrating classical pedology, soil physics, and hydrology might produce synergy that could improve integrated investigations of soil-water connections at various geographical and temporal scales. In order to solve (i) knowledge gaps between pedology, soil physics, and hydrology; (ii) multiscale bridging from microscopic to mesoscopic and macroscopic levels; and (iii) data translations from soil survey data-bases into soil hydraulic information, hydropedology is proposed as such a bridge. The quantification of soil structure, preferential flow modelling, landscape hydrology, soil spatial and temporal variability, the quantitative use of field soil morphology for inferring soil hydrology, the mechanisms governing individual and inter-active soil-water processes at multiple scales, pedotransfer functions (PTFs), and other topics are among the areas where knowledge is lacking. To relate processes happening at microscopic (e.g., pores and aggregates), mesoscopic (e.g., pedons and catenas), and macroscopic (e.g., watersheds, regional, and global) levels, hydropedology incorporates the pedon and landscape concepts. Hydropedology also enables the data bridge among soil sampling datasets and the soil hydraulic data required in computational models using methods like PTFs. The integration of scales, data, and specialties is one of hydropedology's theoretically distinctive benefits to integrated soil and water sciences. Hydropedology is expected to help us better comprehend a range of societally significant environmental, ecological, agricultural, and natural resource challenges. They involve precision agriculture, climate change, soil quality, landscape dynamics, watershed management, nutrient cycling, pollutant fate, and the way an ecosystem works. Challenges in hydropedology include fragmented interdisciplinary presentation in soil science and limitations in global soil databases for fully capturing dynamic soil behavior, emphasizing the importance of field validation in SDG-related studies.

Keywords: Hydropedology, Characteristics, Applications, Functions, Challenges.

INTRODUCTION

The intersection of disciplines and a landscape-related viewpoint are essential for examining broad issues as watershed management or various agricultural management practises, according to a growing body of knowledge in the field of study and science society. The pedon is related to all terrestrial environmental processes (hydrological, geological, meteorological, ecological, and anthropological). The stages in the upper soil zone, which includes the land surface covered in plants, rivers, lakes, the root zone, and the deep vadose zone up to the groundwater zone, are particularly dominant in these processes (Zacharias *et al.,* 2009). Pedology and hydrology are two scientific fields that are inextricably linked to the landscape viewpoint. According to Wilding (2000); Buol *et al.* (2011), pedology is a section of soil science which combines and determines the formation, distribution, morphology, and classification of soils as either naturally occurring or artificially altered nature objects. Hydrology, on the other hand, is concerned with the events, distribution, flow, and characteristics of water within and around the Earth's surface as well as its association with both animate and inanimate elements of the surrounding ecosystem (Lin *et al.,* 2006). Hydropedology, which combines the fields of pedology and hydrology, has produced special instruments for addressing environmental problems. Hydropedology is in an ideal spot to handle present concerns related to dealing with land uses impacted by saturated soil conditions, including certain issues that hydropedology experts are not currently aware of or addressing (Vepraskas *et al.,* 2009). In its infancy, the multidisciplinary field of hydropedology connects soil science with hydrology (Lin, 2003). It discusses spatially and temporally distributed interacting pedologic and hydrologic processes and features in the Earth's Critical Zone. In order to give a more comprehensive knowledge of the interactions between the pedosphere and the hydrosphere, hydropedology strives to cross disciplines, scales, and data, combine soils to their surrounding landscape, link rapid and sluggish processes, and combine modelling with tracking and modelling (Ma *et al.,* 2017). The field of hydropedology has advanced significantly during the last 15 years (Li *et al.,* 2018).

But a closer look reveals that there are a variety of intricate interactions between hydropedology and soil biogeochemistry, frequently including the temporal and geographic variation in water, nutrients, and carbon. Oxidation-reduction (redox) chemical cycles play a major role in regulating Earth's biogeochemistry. According to Falkowski *et al.* (2008), organisms get energy through redox processes, which include the transfer of electrons from an oxidised biological species (electron acceptor) to a reduced chemical species (electron donor). The soil's interaction with water and soil texture affects the pace and chemical routes of these biogeochemical events in a subtle but significant way. The quantity of power that soil microorganisms may extract from the process of oxidation-reduction is frequently governed by hydrology, plus more particularly, by its impact on material diffusion (Hedin *et al.,* 1998; Castellano *et al.*, 2012). The purpose of this presentation will thus be to give a brief overview of the history of the development of hydropedology, to highlight some of the most important research findings and applications, and to indicate future research directions for this multidisciplinary area.

WHAT IS HYDROPEDOLOGY ?

A field of soil science and hydrology called hydropedology examines the interactions between pedologic and hydrologic processes and elements in the Earth's near-surface natural ecosystem. It responds to the following two important queries: 1) How can soil structure and soil dispersion affect hydrologic techniques, along with related biogeochemical dynamics and biological processes at the first-order level? and 2) How do soil creation, development, variation and function throughout space and time are influenced by hydrologic processes and the transmission of material and energy that goes along with them *?* (Lin *et al.,* 2015).

The field of hydropedology is the product of the fusion of soil physical theories, soil genesis theories, and associated facts (Kutílek, 1966). According to Lin (2004), who provide a more thorough and specific explanation of the goals of hydropedology, "Hydropedology is an intertwined branch of soil science and hydrology that encompasses multiscale basis and practical study of dynamic hydrologic processes and the characteristics of soils in the unsaturated zone (Kutílek and Nielsen 2007).

The future viability of the earth's critical zone has been noted as one of the common factors by a wide range of politicians, scientists, and ecologists addressing the major issues of the twenty-first century. The top of the earth and its plant canopy, rivers, lakes, and shallow oceans are all included in its range, as well as the root zone, deep vadose zone, and ground water zone. The connections within the solid earth and its fluid envelopes here affect the access of almost all resources necessary for maintaining life, according to Lin (2004). Since both soil and water are essential elements of this important zone, it makes sense to expand the study of soil hydrology and soil physics by taking real field soil characteristics into account while convolutioning the origins of soil (Kutílek and Nielsen 2007).

CHARACTERISTICS OF HYDROPEDOLOGY

It is feasible to create a significant synergy by combining pedology with soil physics and hydrology, say Lin (2011); Kutilek & Nielsen (2007), when considering the idea of hydropedology as the interaction between the pedosphere and the hydrosphere. According to Lin (2011), the two main areas of interest in hydropedology are: a) how can the soil's physical, chemical, and biological characteristics in a particular landscape (watershed) exert control over the key hydrological processes. How may soil formation processes, their development, and geographical variability be influenced by hydrological processes (hydrological cycle) in a landscape (Mello and Curi 2012). The initial interaction among pedology and hydrology might be viewed as the overall structure of the soil starting at the microscopic to the macroscale point, taking into account the solid parts (texture, aggregation, and horizons), the permeable space, including pore dimensions dispersion, pore morphology, and their interaction networks, the fluid, gases, and biological section within porous space, as well as the interfaces that link the solids components and the porous space (Mello and Curi 2012). Such connections, according to Lin (2011), are key processes for the establishment of optimal flow in the soil surface or zones that are often active for biological reactions. The Brazilian literature lists a number of constraints on water flow that pertain to particular soil strata. Such constraints slow down the flow of water, encouraging a reduction in the flow in the direction of aquifers and the saturated zone while significantly increasing base flow, and lateral flows (Mello and Curi 2012). The soils consist of a variety of horizons, and everyone has a distinctive shape. In other words, the organisation of the mineral particles along with the organic and liquid compounds in the soil characterise it, along with the related pores and aggregates, and subsequently, the porous space for the geobiochemical processes that are examined in this surroundings. The soil profile in this situation exhibits significant variety, and almost all soils exhibit preferential flow (Mello and Curi 2012).

Rekindled interest in movement and transfer through soils and over landscapes is being driven by rising worries about chemical contamination in the environment. Despite the substantial advances made in recent decades, the procedures for transport that take place in structured soils and fractured geological materials, which are crucial to safeguarding nuclear waste and toxic-chemical disposal sites as well as preserving water resources, are still poorly understood (NRC, 2001d). Uncertainty exists about the regulations governing both individual and collaborative soil processes at various sizes. Below are some further instances of knowledge gaps that call for pedology and soil physics/hydrology integration (Lin, 2003).

a) Soil Structure: Essentially to measure the influence of soil structure and water movement. Since procedures related to the hydrological cycle take place on a watershed scale and the soil arrangement and its impediments to water movement occur inside the soil profile, this is one of the major challenges of hydropedology, or how to connect this information to the models and theories of hydrology. In order to more effectively contribute to the study of the flows in watersheds, a new basis for the soil porous media geometry consists of a field that has to be developed (Mello and Curi 2012).

b) Preferential flows: There are additional significant hydropedological difficulties that are linked to soil structure, particularly in headwater landscapes (watersheds) with native forest cover. In reality, preferred flows are characterised as an aspect of the soil structure's behaviour in conjunction with the biological and chemical characteristics of the soil. Under the circumstances, the identification does not adequately reflect how the contact with the soil matrix behaves. To distinguish the soils based on the water flow patterns in the soil profile, a technical or interpretive soil classification system may be created. Fundamental knowledge of the hydrological behaviour of the soil under permanent usage with native forest at high altitudes depends on the results of this work. Nogushi et al. (1997) state this is widely acknowledged that the formations of these preferential flows is a component of a more complicated hydrological system and add that it is impossible to fully comprehend the hydrology of these environments using the current theories and the limited amount of field data.

c) Hydromorphology of the soil: In order to support conclusions about the behaviour of soil structure and, ultimately, better comprehend soil hydrology, particularly its hydraulic properties (saturated hydraulic conductivity, drainable porosity, etc.), pedology may use both macromorphology and micromorphology. This aids in the mechanisms of soil classification and genesis. The morphological properties of the soil, which provide considerably more pertinent information than traits like aggregate uniformity and obstruction, are crucial in determining the behaviour of water flow in the soil profile. There is still a hole in the analytical application of this knowledge, or how to represent the soil morphology for its incorporation into hydrological models. This statistical knowledge related to the soil morphology and micro relief can be obtained through ongoing gathering of field data related to the water table level and soil moisture as well as through the continuous application of remote sensing methods and computerised tomography. This allows one to conclude about the different soil classes by way of their drainage details and other properties like saturating hydraulic conductivity.

d) Movement of water on the surface of a watershed: Parts of hydropedology that require further comprehension include the flow of water under various surface situations in a given landscape and the effects of flows on pedologic processes and, subsequently, on the spatial variability of the soil. In this regard, Lin (2011) notes that the creation of conceptual models for how water moves on the surface is crucial to comprehension of the flow of contaminants, the overall condition of the water, the management of watersheds, and recognising and demarcation of lowland regions. In order such, the author argues that the combination of pedology with surface hydrology and geomorphology can result in sound conceptual models that go above the straightforward application of equations or hydraulic models of flow propagation in channels or laws relating to groundwater movement, such as the Darcy-Buckingham law and the Brooks and Corey equation. In fact, the hydrological models base their structure solely on the aforementioned principles, and they attribute all the intricacy of a process like this to the empirical calibration of models based on actual flows. Because of this, the relationship between these flow sections and overland flow is not well understood, which encourages inaccurate simulations of the land use in a particular area. Large intervals for the same parameter can be produced when the same model is applied to several settings as evidence of this predicament. As a result, the hydrologists have been troubled by the following question: how can the fluctuation of an unknown parameter be explained using the physical processes of the hydrological cycle and, in particular, soil hydrology? The discipline of hydropedology acting likely has the key to the solution (Mello and Curi 2012).

APPLICATIONS OF THE HYDROPEDOLOGY

Coupling Biogeochemistry and Hydropedology to Advance Carbon and Nitrogen Cycling Science. It is evident that hydropedology affects nutrient delivery and transformation through interactions with biogeochemistry. The study of relationships among flow rates, mechanisms for transferring materials, and biogeochemical change in relation to soil structure is progressing. These relationships are essential for foreseeing and controlling how severe precipitation may affect biogeochemical transport and transformation.

Biological mechanisms have been the main focus of ecological theories for N transport and transformation in forested watersheds (Mitchell, 2001; Lovett *et al.,* 2002). Early research (Aber *et al.,* 1989) suggested that vegetative uptake served as the primary ecosystem N sink. But later research (Nadelhoffer *et al.,* 1999) demonstrated that soil organic matter is also a significant N sink. As a matter of fact, numerous unmanaged ecosystems maintain the bulk of N inputs in the soil, converting mineral N (mostly NO_3 and NH_4) into relatively nonreactive stable organic N (Aber *et al.,* 1989; Goodale *et al.,* 2000). These findings prompted the creation of the ecosystem N retention hypothesis, which focuses on the mechanisms of mineral N absorption situated in the soil that mediate N retention. The following significant findings were made, according to Perakis and Hedin (2002): 1) a negative correlation between soil C/N ratios and watershed NO_3 exports; 2) a positive correlation between soil C/N ratio and mineral N retention; and 3) a predominance of dissolved organic N (DON) export rather than NO 3 from pristine ecosystems. Several findings' explanations have highlighted the significance of biotic and abiotic processes. Biotic processes concentrate on the struggle for mineral N among plants and microorganisms, leading to tight cycling and little mineral N loss (Kaye and Hart 1997).

By combining ecological and hydrologic research approaches, hydropedology can explain further heterogeneity in ecosystem N retention. A function for hydropedology is highly supported by current ecological studies. According to certain research (Lovett *et al*., 2004; Castellano *et al.,* 2012), the capacity of soil texture and mineralogy to influence the movement of solutes and adsorption may conceal or remove correlations between C/N ratios and nitrification or NO_3 leaching.

Furthermore, "hot moments" of dissolved N losses that take place during major precipitation events and result in disproportionately high N fluxes at pedon and watershed scales cannot be explained by ecosystem N retention hypothesis. Rapid flow is likely greater than the kinetics of dissolved N immobilisation in these circumstances (Lovett and Goodale 2011).

When evaluating N movement and transformation, hydropedology can combine ecological and hydrologic views on N biogeochemistry by taking into account the connections between soil structure, flow routes, and hydrology. It is widely known that flow pathways can influence biogeochemical cycling on a large scale by directing water flow across regions with various reactant availability (Hill, 1996). For instance, the denitrification and conversion of substantial volumes of NO_3 into DON can occur when a hydrologic flow channel crosses a C-rich riparian buffer (Castellano *et al*., 2012).

Soil Water in the System of Hydropedology. The underlying structure of the organization of the solid phase, the makeup of the soil bone structure, and the layout of pores throughout the soil system hold the key to understanding why soil hydraulic characteristics vary in different pedotaxons. Yet in respect to their significance, quantifiable correlations between morphologic aspects of soil structure and soil hydraulic functions are currently insufficient. Both efforts to link qualitative assessments of micro-morphological aspects to unsaturated conductivity measures and those to link soil fluxes to macro-morphological elements of soil structure have been successful (Lin *et al.,* 1999; Vervoort and Cattle 2003).

Horn *et al.* (1995) also looked at the relationships between micromorphological traits and operations and soil structure. Additionally, a quantitative assessment of soil bi-modal porosity and its link to soil hydraulic functions (Othmer et al., 1991) has increased our understanding of the impact of soil structure on soil hydraulics and hydrology. However, if study on a larger scale of soil taxons is to be conducted, we must look for physically based information on the links between soil taxa and soil hydraulic processes (Kutílek and Nielsen 2007).

Hydropedology and pedotransfer functions. Collaboration between disciplines and a landscape-related viewpoint are essential for examining cross-cutting concerns like handling watersheds or various agricultural management practises, according to a growing body of knowledge in the research and science community. The pedon is related to all terrestrial environmental processes (hydrological, geological, meteorological, ecological, and anthropological). The events that occur in the upper soil zone, which includes the land surface covered in plants, rivers, lakes, the root zone, and the deep vadose zone up to the groundwater zone, are particularly dominant in these phases. The bulk of natural and biological operations, includes all types of land use (such as agriculture and urbanisation), precipitation, groundwater replenishment, and mass flow, occur in this region. The National research Council (NRC, 2001) named this region as the "Critical Zone" as a result, and it is one of the dominant study fields of the twenty-first century. For multidisciplinary study on the earth's surface, a supporting framework is offered by the "Critical Zone" - Concept as a system concept.

The majority of the bio-geophysical and chemical reactions between the earth's surface, the lower atmosphere, the soil, and ground water occur at reactive interfaces that are covered by the Critical Zone. Considering the processes at play in this zone is essential for comprehending pertinent ecological dynamics and operations. It creates the foundation for the management of sustainable water and land resources. However, anthropogenic-driven processes are equally important for the condition of the Critical Zone as natural ones. More frequently than not than not, anthropogenic influences on soils define its key components. Therefore, proper assessment of human changes, such as changes in land use and the consequent increasing influence on water and land resources, is required in modern environmental models. It is essential required to bridge classical pedology, hydrology, soil physics, and other related disciplines in order to address the issues brought on by concerns about soil and water at different geographical and temporal scales. The idea of hydropedology, which combines knowledge and experience in the domains of pedology, soil physics, and hydrology, has gained considerable attention in recent years (Lin, 2003; Lin *et al*., 2006; Wilding and Lin 2006). Many of the traditional scientific methods take each of these elements into account independently (Zacharias *et al.,* 2009).

Developments of groundwater recharge indicatormaps: The soil-landscape interactions, which include the index, were also connected to various soil uses since they are essential to defining certain soil characteristics connected to the replenishment of groundwater. In this case, the author relied on the finding by Alvarenga *et al.* (2011) that native forests at the Mantiqueira Range exhibit superior conditions for water penetration and redistributing than extensive pastures and annual crops. For the same soil-landscape condition, the native forest conditions produced saturated soil hydraulic conductivities that were up to five times higher than those of the pastures (Mello and Curi 2012).

Future directions for hydropedology: Quantifying impacts of global change on land use

The field of hydropedology is ideally suited to handle current problems brought on by climate change. We suggest a six-step procedure for creating digital, field-scale maps that illustrate where the largest consequences of climate change would be seen for two types of land uses: wetlands and housing sites with septic systems. Critical water table levels have been established by state and federal legislation, and they may be used to predict whether septic systems will work well or not, as well as the likelihood of wetlands. Long records of water table data may be computed using hydrologic models, historical rainfall, and temperature data. However, because there hasn't been enough research done to consistently evaluate various methods for accomplishing this, it is challenging to extrapolate such data across geographical regions. The modelled water table data may be used to specify soil drainage classes for specific mapping units, and utilising the drainage classes, available digital soil survey maps can be used to extrapolate the data regionally. The models may also take into account estimates of variations in humidity and precipitation to calculate adjustments to the water table levels and drainage classes. More work has to be done on creating daily climate files from the monthly climate change projections in order to achieve this efficiently.

The NRCS Soil Survey Geographic (SSURGO) Database may now be used with hydrologic model projections to create maps inside a GIS that highlight the effects of climate change on sewer system operation and wetland borders. These maps will provide planners the ability to either limit development in vulnerable regions or merely keep an eye on the water quality in these areas for harmful organisms.

The Coastal Plain region should benefit from using forecasting maps and calibrated models. Hydropedologists may be able to contribute significantly with comparable work on additional climate change and land-use challenges (Vepraskas *et al*., 2009).

Frontiers in Hydropedology: Interdisciplinary Research from Soil Architecture to the Critical Zone

Soil Architecture and Subsurface Water Flow. The geophysical investigation of soil structure and subsurface water movement is the primary emphasis of the first theme. Complicated relationships among various hydrologic processes, soil moisture dynamics, subsurface water flow, and solute transport result from heterogeneous soil composition. However, the timing and location of subsurface lateral flow are quite unknown. By analysing intricate connections between erosion-affected pedologic and regionally variable hydraulic features and circumstances in a hummocky agricultural soil environment in northeastern Germany, Filipovic *et al.* (2018) were able to quantify the potential for subsurface lateral flow. The transfer of water and dissolved substances in the unsaturated zone depends on preferred flow, but current observational techniques to identify and measure preferential flow are insufficient.

In order to improve the precision of using geophysical approaches to highlight the complexity of preferred flow at the Hillslope scale in a wooded catchment in Pennsylvania, Nyquist *et al.* (2018) combined ground-penetrating radar with dye tracer infiltration. In a karst watershed in southwest China, Yue *et al.* (2018) employed stable isotopes of water and nitrate to pinpoint nitrate sources and evaluated seasonal fluctuations in hydrological processes impacting nitrate levels in surface and subterranean systems (Li *et al.,* 2018).

Groundwater–Surface Water Interactions. The interactions between groundwater and surface water are the second subject. Because of geographical heterogeneity and difficulties detecting hydrological processes at various scales, quantifying groundwater-surface water interactions is challenging.

While soils are essential to the hydrological operation of landscapes, very few studies of groundwater-surface water interactions have focused on soils as important factors in comprehending hydrologic variability. In South Africa, 21 catchments with accessible stream characteristics and hydrological variability were analyzed by Van Tol and Lorentz (2018). A study of the soil hydropedological circulation pattern, they suggested three conceptual frameworks of groundwater-surface water interactions: (i) those where vertical drainage through soils and recharge of groundwater are dominant in upper slopes, with return flow to soil layers in lower lying positions, and both soil and groundwater contributing to streamflow; and (ii) those where vertical drainage through soils and recharge of groundwater are dominant in both upper and lower lying lands (Li *et al.,* 2018).

HYDROPEDOLOGY AT DIFFERENT SCALES

Numerous applications need for knowledge of soil moisture levels and water flow in soil volumes that are either too big or too tiny to be measured directly. Discrepancies characterising scale impacts on soil moisture and soil hydraulic characteristics is necessary due to the disparity across the various levels where soil water quantity and flow information are required and at which they are accessible. Range definitions in hydrology and soil science are not the same. Additionally, pedology and hydrology may use several mapping scales within the same area or continent. The difficulty of linking soil structure and soil hydraulic functioning at various scales can be presented for similar geographical units, yet scale disparities are reconcilable (Pachepsky *et al*., 2008).

Aggregate/Ped Scale. The soil-moisture holding curves, which represents an effective link among the volume of water held in soil pores and the capillary pressure at air-water interactions, has historically been used to describe soil structure. The mercury-based porosimetry curve, a visual depiction of the connection within the entire volume of empty pores and the capillary pressure at the menisci in the smallest pores that still contain water at this level of pressure, is a very comparable structural property. The geometry of the void space, which reflects linkages among pores and tortuosity that flows through pores, is connected to the water retention property in terms of the soil's capacity to conduct water and redistribute solutes in the void space. The impoverished hydraulic conductivity (Kunsat) is the primary hydraulic parameter in the most recent models of flow in unsaturated soils. The no-connection capillary bundle model, which in some situations makes logical assumptions, was the first model to obtain Kunsat from the soil-moisture retention curve, followed by the model of irregularly linked capillaries.

Horizon/Pedon scale. Instead of describing voids, most field soil analyses characterise the structural arrangement of solids. Although complimentary, descriptions of the pore space's structure and those of solids are not at all comparable. However, scholars who utilised qualitative evidence of type, size, and grade of soil structure to estimate soil hydraulic properties or to assess the structural state of the tilled layers and their impact on water movement by mapping predetermined types of soil clods recognised the significance of the knowledge contained in visual descriptions of soil structure. It has been published and frequently utilised to draw useful regional and national conclusions. The remarkable feature of soil water repellent effect calls for this level of hydropedological research. Although it is now well acknowledged that its origins lie in the deposition of long-chain organic molecules on or between soil particles, knowledge of their precise chemical make-up and methods of attachment to particle surfaces is still lacking. An outstanding illustration of the necessity to incorporate biotic and biogeochemical studies in hydropedologic analyses is soil water repellency.

Field/Hill slope Scale. Lin *et al.* (2006) suggested a thorough characterization of the connections among soil structure and hydrologic activity at this scale. The four primary flow channels downslope that their model depicts are flow at the soil-bedrock interface, return flow at the footslope, flow at the toeslope, and subsurface macropore movement at the A-B horizon contact. The investigators claim that instead of the sheet flow that is frequently used in many hydrological models, all four paths are depicted by preferred flow channels (Pachepsky *et al.*, 2008).

Watershed/Basin Scale. The choice of structural and functional factors is a key challenge at this scale. The base flow index (BFI), which measures the volume of baseflow as a percentage of the overall flow volume, was chosen by Boorman *et al*. (1995).

Eleven conceptual models of soil hydrologic responses that are pertinent to soil function as a source of water for streams were identified by the authors. The existence of the surface organic horizon, the presence and location of the gley layer, the presence and location of the slowly permeable layer, and the combined soil air capacity were the criteria used to differentiate among the structures.

Transcending Scales. The choice of structural and functional factors is a key challenge at this scale. The base flow index (BFI), which measures the volume of baseflow as a percentage of the overall flow volume, was chosen by Boorman *et al.* (1995).

Eleven conceptual models of soil hydrologic responses that are pertinent to soil function as a source of water for streams were identified by the authors. The existence of the outermost organic horizon, the presence and location of the gley layer, the availability and location of the slowly permeable layer, and the combined soil air capacity were the criteria used to differentiate among the structures. A technique for going beyond soil and hydrologic recently, scales were put out by Vogel and Roth. This approach, known as "scaleway", acknowledges that hierarchical organisation may be seen in both soil structure and soil hydrologic functioning characteristics. The scale way is predicated on the following assumptions: (a) structural units at the scale of interest are readily apparent and distinct; (b) structural units are connected to particular material properties that regulate flow and transport; and (c) the material characteristics controlling flow and move within structural units can be computed using unpredictable representation of the finer scale structure within the structural units with a suitable flow and transportation method (Pachepsky *et al.*, 2008).

FUTURE CHALLENGES

Two major challenges stand out. First, the collaboration between pedologists and soil physicists, particularly in hydropedology, needs to extend beyond the current focus. Soil science, encompassing various subdisciplines, should be presented cohesively to scientists in other fields. A logical sequence, starting with pedology and progressing through hydropedology, would provide a more comprehensive understanding of soil behaviours for stakeholders and policymakers. Second, while the availability of soil characteristics for global grid cells (e.g., 250 by 250 m) is valuable, these databases have limitations in representing dynamic hydropedological soil behavior in a landscape context. Field validation remains crucial to determine the suitability of data and models for hydropedological applications in the context of SDG-related studies (Bouma, 2016).

SUMMARY

Due to its interdisciplinary nature and use of contemporary methodologies, hydropedology represents a conceptual and methodological advancement that is essential for the growth of various Geosciences disciplines of inquiry. Its applications cover a wide range of fields of study related to soil science, hydrology, and geomorphology. The study of interaction pedologic and hydrologic processes and features in the earth's critical zone is proposed to be the focus of hydropedology, a branch of soil science and hydrology that integrates multidisciplinary and multiscale techniques. Here, it is important to note potential "bridges" that could be used to address three issues: 1) knowledge gaps between conventional pedology and soil physics/hydrology; 2) scale disparities in microscopic, mesoscopic, and macroscopic studies of soil water interactions; and 3) data conversion from soil survey databases into soil hydraulic properties. Such connections represent the potential for distinctive contributions from hydropedology to interdisciplinary soil and water research. Since the 21st century places a strong emphasis on interdisciplinarity, understanding hydropedology also benefits the education of the next generation of soil scientists and vadose zone hydrologists.

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